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Kinematic Analysis of the Racket Position during the Table Tennis Top Spin Forehand Stroke

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Abstract: The present study aims to assess the position of the racket, and racket height with respect to the floor, during the table tennis top spin stroke. A stereophotogrammetric system (Smart-D, BTS, 8 cameras, 550 Hz) was used to track the table tennis racket during cross-court (CC) and long-line (LL) shots. Ten national level players completed ten CC and ten LL top spin strokes responding to a robot machine. The racket motion throughout the shot showed specific technical characteristics: the minimum height of the racket was detected during the backswing phase; racket height at the end of backswing phase (maximal distance racket/table) was higher than the minimum; height at the racket maximum velocity (ball/racket impact) was greater than the net's height. Furthermore, the maximum height of the racket occurred at the end of the forward swing. No differences in these kinematic variables between CC and LL were found. Conversely, a higher inclination of the racket at the moment of maximum speed was detected in LL vs. CC. From a practical perspective, the present findings suggest that table tennis players need to introduce specific exercises in order to increase the height of the racket during the forehand top spin stroke, to improve its effectiveness.

Keywords: kinematics; technique; racket sports; table tennis

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1. Introduction

The top spin forehand is one of the most aggressive shots used in table tennis [1]. It is characterized by fast rotation and high speed of the ball [2]. The top spin forehand is also the most frequent shot used in top-level table tennis matches, followed by the top-counter-top forehand [3].

The kinematic analysis of the table tennis top spin forehand stroke has been addressed in many previous studies. Iino and Kojima [1] assessed segmental and joint angular speeds during the forehand top spin shots against backspins (light and heavy) in advanced athletes. These authors found that a slight delay between the upper and the lower trunk during axial rotation was optimal for the outcome of the top spin shot. Moreover, a correct execution of the top spin was associated with high angular velocities [1] and with a high energy transfer from the pelvis to the racket arm through the upper body and rotation of the upper limb [4].

More recently, Malagoli Lanzoni and colleagues [5] compared the kinematics of the long-line (LL) and cross-court (CC) top spin forehand shots, and angular variables of the trunk with respect to the table. In LL as compared to CC, they observed more flexed knee and elbow angles and more evident rotation angles of the lower- and upper-body with respect to the table. These differences are likely due to the more rotated position of the entire body with respect to the table tennis table and to the position of the feet in relation to the position of the table. These positional changes may influence other performance variables [5].

Besides the athlete's kinematics, the racket speed is considered a key indicator of efficacy of the top spin forehand shot in elite table tennis players [6–9]. Moreover, the racket speed and swing motion may be affected by duration frequency of shots and rally time [10]. Since a high shot frequency may enhance the player's performance [11,12], it seems advantageous for table tennis players to be able to quickly accelerate the racket when hitting the ball. Moreover, keeping the racket high and reducing the range of motion during the top spin shot may be a useful strategy to intercept the ball during very fast rallies and perform an effective return shot. Indeed, table tennis coaches usually suggest training exercises with CC and LL strokes, emphasizing holding the racket high with respect to the floor. Keeping the racket high would seem more natural in LL as compared to CC shots, because the distance between the player and the target is shorter and the target is closer to the net. However, a limited number of studies have assessed the position of the racket during the top spin forehand stroke [1,2], and these studies have examined only CC top spin shots.

Thus, the aim of the present study was to evaluate the position of the racket, and its height with respect to the floor, in CC vs. LL top spin forehand executions in table tennis. We hypothesize that the height of the racket with respect to the floor is different in CC and LL top spin forehand executions, respectively. We also hypothesize that the inclination of the racket at the moment of maximum racket velocity (racket-ball impact) is different, when comparing the two executions.

2. Materials and Methods

2.1. Participants

Ten table tennis male competitive athletes (age: 22.7 ± 7.4 years; body mass: 74.2 ± 10.7 kg; body height: 177.3 ± 4.4 cm) volunteered to participate in the present investigation. The participants had 10.0 ± 1.8 years of experience in competitive table tennis and were classified among the top 200 players in the Italian table tennis ranking. All players were right-handed and used shake hands grip rackets. Figure 1 shows the traditional shake hand grip adopted by all the participants from a European school of training. Indeed, exclusion criteria included any type of different grip (pen-hold grip: Chinese, Japanese, and Korean). The dominant hand of the players was established according to which hand was used to hold the racket [13]. Moreover, all the players adopted an offensive playing style because they did not use long-pimple rubbers, the typical rubbers used by defenders, and a backhand chop stroke when playing far from the table during official competitions.

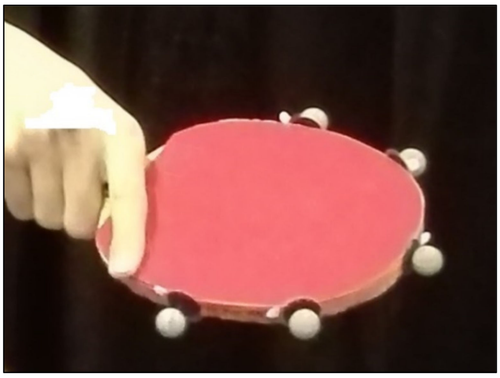

Figure 1. The shake hands grip used to hold the racket and marker placement on the table tennis racket.

Subjects were asked not to consume caffeine for at least 4 h prior to the data collection sessions. The testing procedures were fully explained to each subject prior to the experimental procedures. Exclusion criteria included injuries of any type that occurred in the six months before the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Bologna University, Italy (Project identification code: 0061178, 15 March 2021). All the participants provided their written informed consent to participate.

2.2. Experimental Procedures

Figure 2 shows the laboratory set-up with the two targets of 40 × 65 cm, traced upon an ITTF approved playing table tennis table [5,14].

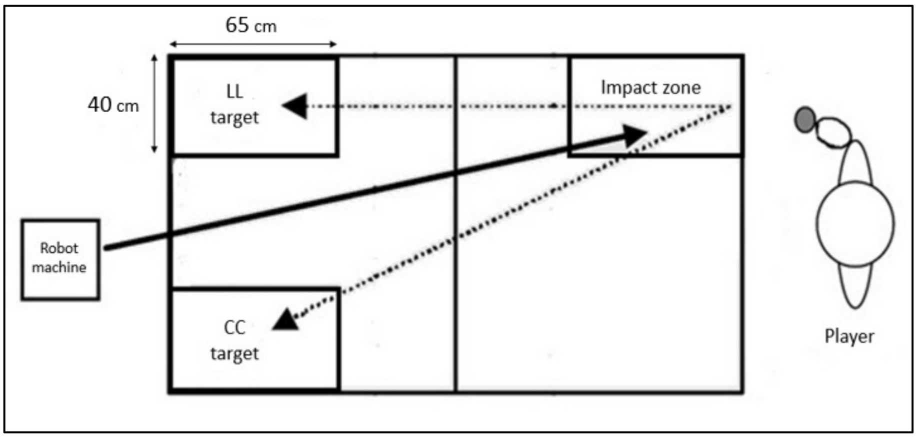

Figure 2. Experimental set-up of the laboratory.

All players used the same table tennis racket (Blade: Butterfly Primorac off, Tamasu, Japan) with the same covering material (Butterfly Tenergy 05 Max rubber sheets, Tamasu. Japan) in order to avoid any influence of the materials on the examined kinematic parameters.

After a standard warm-up (5 min cycling at 50 W), the participants were asked to return balls delivered by a table tennis robot machine (Joola Compact, Joola Company, Siebeldingen, Germany) for a preliminary familiarization with procedures. The robot machine was set at speed level 7 and frequency level 1 and projected the balls towards an impact zone (40 × 65 cm). The machine was located in the middle of the table at the other side of the court. Then, the subjects were asked to play a forehand top spin to the two targets placed on the other side of the table tennis table (cross-court = CC, long-line = LL). Trials were completed when the player precisely played ten shots on the left target (CC) and ten shots on the right target (LL). Only the shots on the two targets were considered for analysis. The players were asked to start with a set of CC shots followed by a set of LL shots. A two-minute break was included between sets. No instructions were given to athletes at the beginning of the trials related to how to place the racket and the body before, during and after shot executions, so as to not influence the technique. This procedure allowed for consistency in the way the balls were hit by the players and provided a more natural setting.

2.3. Kinematics

A stereophotogrammetric system was used to track the segment poses during motion (SMART-DX 7000; BTS S.p.a.; 8 cameras; 500 Hz; software version 1.10.451.0; Garbagnate Milanese 20024, Milan, Italy). The calibrated acquisition volume was 4.5 × 4.0 × 2.5 m.

Four markers were attached on the table. Regarding the system of reference of the table, the x axis was the center line, the y axis was the end line of the table, and the z axis perpendicular to the table plan [5].

Regarding the racket, 5 markers were placed on the edge of the racket to form a technical cluster. Figure 1 shows the position of the markers on the racket. The center of the racket was calculated as the centroid of the 5 markers. The coordinate of the center of the racket was expressed both in m and as a percentage of the height of the participants to account for the influence of anthropometric differences.

For the hand-table tennis racket segment, the y axis was aligned with the grip, the z-axis was perpendicular to the racket plate, and the x axis consequently.

The orientation of the racket with respect to the table was obtained by decomposing the relative orientation of the racket with respect to the table using the zy′x″ Euler angles (RZ, RY, RX). Therefore, RZ represents the rotation of the racket around the axis perpendicular to the table, and 90° and 180° correspond to the alignment of the racket with the center line and end line of the table, respectively.

The variables listed below were measured in relation to the two different types of executions, CC and LL, respectively:

- H-Min: Minimum height of the center of the racket with respect to the floor. Expressed in m and as a percentage of the height of the athlete;
- H-RT: height of the center of the racket with respect to the floor at the moment of the maximum distance between the racket and the table. Expressed in m and as percentage of the height of the athlete;
- H-MMV: height of the center of the racket with respect to the floor at the moment of maximum velocity of the racket (MMV). Expressed in m and as a percentage of the height of the athlete;
- H-Max: Maximum height of the center of the racket with respect to the floor. Expressed in m and as a percentage of the height of the athlete;
- Rx-MMV: rotation of the racket in the x axis at the moment of maximum velocity of the racket. Expressed in degrees;
- Ry-MMV: rotation of the racket in the y axis at the moment of maximum velocity of the racket. Expressed in degrees;
- Rz-MMV: rotation of the racket in the z axis at the moment of maximum velocity of the racket. Expressed in degrees;

A model representation of the H-Min, H-RT, H-MMV, and H-Max measurements is shown in Figure 3.

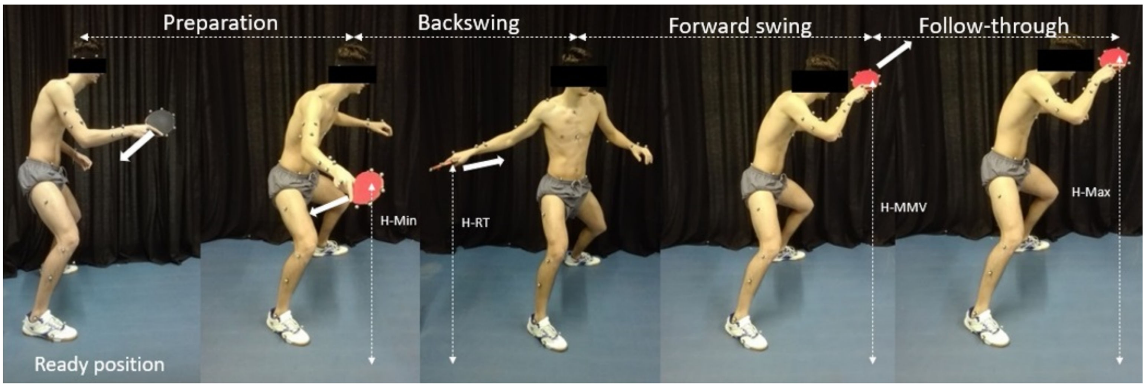

Figure 3. The movement sequence of the table tennis top spin forehand including measured variables (H-Min, H-RT, H-MM, and H-Max) and different phases (preparation, backswing, forward swing, and follow-through).

2.4. Statistical Analysis

The statistical analysis was performed using SPSS version 25 (Chicago, IL, USA).

For all variables, data are reported as mean value ± SD considering the two examined conditions (CC and LL). After the assumption of normal distribution of differences was verified with Kolmogorov–Smirnov tests ($p > 0.05$ for all examined variables), the mean values were compared using Student's t tests for paired data (significance was set at $p \leq 0.05$).

3. Results

Table 1 shows the mean values of the kinematic variables measured in the CC and LL conditions, respectively. H-Min and H-RT, when expressed both as absolute and normalized distances, showed a moderate degree of variability, with CVs ranging from 14.8 to 25.2%, while variability was lower for all other examined variables (CV < 9%). No significant differences between the two shot executions were observed for H-Min ($p = 0.82$), for H-RT ($p = 0.64$), for H-MMV ($p = 0.62$), H-Max ($p = 0.56$), and maximum racket velocity ($p = 0.54$). Moreover, no significant differences were also observed for Rx-MMV ($p = 0.77$), and Ry-MMV ($p = 0.79$). Furthermore, Rz-MMV was significantly lower in CC than in ($p = 0.00$).

Table 1. Mean SD values of the examined kinematic variables in both the CC and LL conditions. CC = cross-court; LL = long-line. * $p < 0.05$.

Variable	CC (Mean ± SD)	LL (Mean ± SD)	*p*
H-Min (m)	0.53 ± 0.12	0.53 ± 0.13	0.82
H-Min-norm (%)	30.0 ± 7.2	30.1 ± 7.6	
H-RT (m)	0.60 ± 0.09	0.61 ± 0.09	0.64
H-RT-norm (%)	33.9 ± 5.9	34.2 ± 5.9	
H-MMV (m)	1.08 ± 0.05	1.09 ± 0.05	0.62
H-MMV-norm (%)	61.0 ± 3.3	61.3 ± 3.4	
H-Max (m)	1.63 ± 0.08	1.62 ± 0.08	0.56
H-Max-norm (%)	91.9 ± 4.7	91.6 ± 5.2	
Rx-MMV (°)	−154.1 ± 13.2	−155.8 ± 9.1	0.77
Ry-MMV (°)	29.8 ± 2.5	30.4 ± 1.6	0.79
Rz-MMV (°)	148.6 ± 6.6 *	161.8 ± 5.3	0.00
Max Racket velocity (m/s)	13.94 ± 0.67	13.79 ± 0.58	0.54

4. Discussion

This study aimed to compare the height of the racket with respect to the floor between two different types of shots (CC vs. LL). We hypothesized that the height of the racket with respect to the floor was different in CC and LL top spin forehand executions, respectively. We also hypothesized that the inclination of the racket at the moment of maximum racket velocity (racket-ball impact) was different, comparing the two executions.

A limited number of studies have evaluated the height of the racket in the top spin forehand stroke [1,2], and all studies have only assessed CC shots.

A previous study [2] analyzed the relative temporal structures of the rotative and striking top spin strokes and defined the range of movements along the anterior-posterior and vertical axes. The results showed that the racket covered the same horizontal distance in both rotative and striking top spin. On the contrary, a difference in vertical range was detected between the two shots. Indeed, the amplitude and localization of the key points (start, end of preparation, impact and end of movement) were different according to the players and the stroke used.

Iino and Kojima [1] investigated the racket kinematics at ball impact, and the ball height at impact was measured as the distance between the racket and the floor. They did not show any significant effect of participants performance level on the racket kinematics and ball speed after impact. On the contrary, advanced players adjusted racket/ball impact height to the different spins, 0.988 ± 0.072 m and 1.034 ± 0.037 m, against light and heavy spin, respectively.

Theoretically, players can adjust parameters such as the racket speed, the direction of the racket path, the racket face angle and the height of the impact point, to properly play different shots [1]. Iino and Kojima [1] also measured the speed of the racket at impact comparing advanced and intermediate players, against light- and heavy-spin, respectively. The racket speed at impact was not significantly different between the two player groups but they showed higher speed values compared to the present investigation (i.e., 19.6 ± 1.1 vs. 13.9 ± 0.7 m/s). This information suggests that players need a lowest maximum speed of the racket to play a top spin forehand against no-spin compared with a top spin forehand against backspin, respectively.

However, the results of the present investigation show no difference for some of the measured kinematic variables (H-Min, H-RT, H-MMV, and H-Max) between the two different executions (CC and LL), and does not support our first hypothesis.

Racket motion, in terms of the height of the racket at the key points, seems to show a stereotypical movement pattern and a similar execution between the two considered shots. Zhang and colleagues [15] suggested to divide the top spin stroke in four different phases, which can be defined as preparatory, backswing, forward swing and follow through. Considering this classification, the minimum height (H-Min) is included in the backswing phase. The height of the racket measured at that point (CC: 0.530 ± 0.124 m; LL: 0.533 ± 0.131 m) was lower than the table height (0.76 m).

Moreover, the height of the center of the racket with respect to the floor at the moment of the maximum distance between racket and table (H-RT) was exactly at the end of the backswing and at the beginning of the forward swing. It was higher than the H-Min but still lower than the height of the table (CC: 0.599 ± 0.094 m; LL: 0.605 ± 0.093 m), showing the need to raise the racket at the beginning of the forward swing phase.

Subsequently, at the moment of maximum racket velocity (H-MMV), the racket was higher than the table in both CC and LL (CC: 1.081 ± 0.053 m; LL: 1.086 ± 0.054 m). In the present investigation, the moment of maximum racket speed was considered as the ball-racket impact. Several investigations indeed support the idea that the moment of maximum racket velocity in table tennis shots corresponds to the ball impact [5–7,15,16]. Therefore, the height of the racket at the moment of the ball-racket impact should also be considered greater than the height of the net with respect to the floor (0.76 + 0.1525 = 0.9125 m). A stereotypical movement, in terms of height of the racket at the key points, seems to be also confirmed by normalized data. Moreover, it suggests that the height of the racket during the execution is independent from the height of the players, and it is more influenced by the height of the table. This finding confirms the need to raise the racket at the impact, during the forward swing phase.

The maximum height of the racket with respect to the floor (H-Max) corresponds exactly to the end of the follow through phase. The results showed greater values (CC: 1.628 ± 0.075 m; LL: 1.624 ± 0.084 m) than the height of ball-racket impact (CC: 1.081 ± 0.053 m; LL: 1.086 ± 0.054 m).

Recently, Malagoli Lanzoni et al. [5] compared different kinematic variables in CC and LL forehand top spin executions. Significant differences were observed for lower body variables (angles). In particular, the lower body was more rotated with respect to the table when the shot played was LL compared to CC. Differences in the upper body may also be due to the more rotated position of the whole body with respect to the table. Indeed, the position of the feet seems to influence the other kinematic variables (Malagoli Lanzoni et al., 2018). Furthermore, the greater inclination of the racket at the moment of the impact was measured in LL and may be also related to the final direction of the top spin.

The results of the present study confirm these previous observations, showing a significant difference in the rotation of the racket in the z axis at the moment of maximum velocity of the racket (Rz). The racket inclination, that can be considered a relevant kinematic variable, was more pronounced for LL (161.8 ± 5.3°) with respect to CC top spin (148.6 ± 6.6°). This does support our second hypothesis regarding racket inclination differences comparing the two executions, LL and CC, respectively.

The racket face angle and the direction of racket path have been analyzed comparing the forehand top spin stroke against heavy and light backspin [1]. It was shown that the racket face was more open against heavy backspin than against light backspin [1].

The present findings suggest that the whole position of the body with respect to the table has a primary effect on the kinematics of CC and LL forehand top spin strokes. These results therefore confirm a standardization of the shot and a relevant control of the movements in the examined athletes. This study also shows that the two different top spin executions (CC and LL) have no substantial influence on the height of the racket. This finding indicates a relevant ability of these athletes to adapt and control their technique in relation to different playing conditions. Indeed, participants are able to adapt the whole position of the body with respect to the table and the racket inclination in order to play the same shot using two different targets, without changing the height of the racket. This characteristic may be also related to the level of the players and their experience in competitive table tennis (10.0 $\pm$ 1.8 years).

Many practical suggestions should be communicated by table tennis coaches to athletes in order to enhance the height of the racket with respect to the floor.

Firstly, the height of the racket should be increased by modifying the trajectory of the balls sent to the impact zone by the robot machine. It is also important to maintain a fixed body position to produce a more pronounced technique, in terms of racket height.

Secondly, Iino and Kojima [10] have suggested that the impact location is more forward for a high frequency condition (shots/min) than for a low frequency condition in the backhand top spin stroke. The robot machine set-up should be modified in order to modulate the frequency. Therefore, the impact location may be more forward and high when the frequency increases (shots/min) for the forehand top spin stroke.

Thirdly, different spins (back or top spin) can be used to induce a greater/lower height of the racket during the forehand top spin stroke execution [2]. It seems more effective to play a forehand top spin when returning balls without spin or with a top spin effect with respect to returning balls with a backspin.

Nevertheless, it must be acknowledged that participants in the present study were expert athletes and the results may not be extended to other athletic populations such as intermediate or low-level players.

A limitation of the present investigation may be that the data collected was obtained when the participants were not playing games but simulating play under the experimental constraints. Moreover, the spin rate and the speed of the ball were not measured during the investigation. Furthermore, in order to reproduce a more realistic and interactive table tennis rally, a further research perspective for future studies is to include randomized projection of the balls.

5. Conclusions

Racket motion, in terms of the height of the racket at the key points (H-Min, H-RT, H-MMV, and H-Max) seems to demonstrate a stereotypical movement pattern and a similar execution between the two considered top spin forehand shots (CC and LL). Moreover, the height of the racket at the moment of the ball-racket impact is greater than the height of the net with respect to the floor for during both executions. Furthermore, the inclination of the racket (in the z axis) was more pronounced for LL with respect to CC top spin execution. The findings suggest that the whole position of the body with respect to the table has a primary effect on the kinematics of CC and LL forehand top spin shots.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

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